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DEPARTMENT OF THE ARMY
Fort Detrick
Frederick, Maryland

Aerodynamics - A marked phenomenon of hysteresis in aerodynamics

by R. Mercier

Compt. rend. 246: 5: 698-701: 1958

With the recent experiments on the measurement of the aerodynamic transitory drag coefficients of very small spheres there has been recognized an influence of another parameter besides the instantaneous Reynolds' number, the initial Reynolds' number.

A recent article (1) gives a detailed description of the results of experiments destined to furnish the law of evolution, in a transitory speed, of the aerodynamic drag coefficient (C_x) of very small spheres or droplets as a function of the Reynolds' number R vd/<u>v</u> (v, velocity of spheres relative to the air; d, diameter of the spheres; <u>v</u>, kinematic viscosity of the air); the author is finally led by his measurements to the empirical expression $C_x = 27/R^{0.14}$; this expression is simple and probably sufficient for current needs; but it does not bring out a process which the experiments in effect permit to happen.

The following is the experimental procedure which is used: the small spheres, of specific mass ρ, are introduced on the axis of the stream of a blower at a position 0 - taken as the origin of the abscissas - or they are considered as at absolute rest; the pressure p and the temperature θ in the stream are known and permit the calculation of the specific mass ρ' of the air and of its velocity; in three other positions 1, 2, 3, of fixed abscissas, one measures the absolute velocity u of the particles carried along by the stream of air of velocity u_o.

The article cited gives the curves of velocity as a function of the diameter, at three positions, in 14 experimental cases, which makes it possible to overcome the limitations in taking note of the following observations:

a. The determination of C_x implies a very uncertain differentiation of curves u(x) which are not known except by four experimental points; it is possible then to foresee a sufficient dispersion of the points of the co-ordinates logR and logC_x, in the classical representation in logarithmic co-ordinates of a like modulus, for which one can not hope to do better than to translate empirically their mean position by a simple law C_x A/R^n, A and n being finally the constants to be determined. But then if one admits, at the start, this final representation, one can integrate the movement in the general case and seek directly the values of A and n which, for each diameter best justify the relevant velocities at different points in each case.

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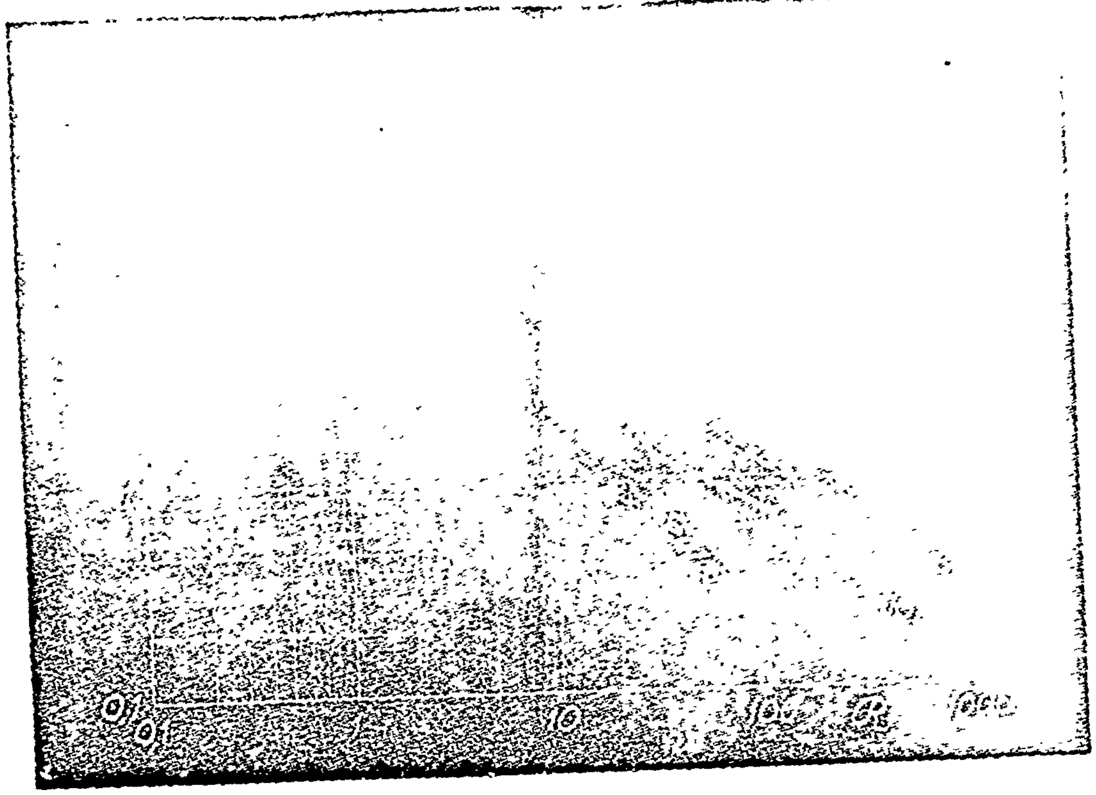

Figure 1

Translator's note: Notice that the broken line upon reaching the line of the permanent law goes along it- not on up --until it is finally in the line representing Stokes' law.

b. Thus having avoided the uncertain differentiation, one soon observes that the findings at three positions (necessary and sufficient to be able to calculate the two quantities* A and n) uncovers a curious phenomenon: the amounts of n do not vary slightly around a mean value of 0.84; n often plainly has the value $\frac{1}{2}$ (between the positions 0, 1, 2). Sometimes it plainly has the value 2 (between the positions 1, 2, 3 for large particles); more often finally it takes different values, but always remains between $\frac{1}{2}$ and 2. This phenomenon can be explained by the sucession for one like sphere in the course of a like experiment, of two laws ($n = \frac{1}{2}$, then $n = 2$) without discontinuity of velocity ($\bar{R}$) nor of acceleration (or C_x); in the representation in logarithmic coordinates, there will be a line broken at a point $C(R_c, C_{xc})$; branching out from the point C the representative segments will be the respective inclination $-\frac{1}{2}$ and -2: $C_x = C_{xc}(R_c/R)^{\frac{1}{2}}$ for $R > R_c$ and $C_{xc}(R_c/R)^2$ for $R < R_c$.

This explanation must be completed, in consideration of a further limitation, in order to suceed when $R \to 0$ according to Stokes' law $C_x = 24/R$. The points such as C reveal themselves all following above the line representing Stokes' law and below the curve admitted for the permanent law determined from numerous investigations $[C_x \sim (28.6/R^{3/4}) + 0.4]$, the most simple thing is to admit that, when the representative point reaches this last curve (of the permanent law) by the segment of incline -2, it assumes it (the line of the permanent law) to find itself finally (for $R < 0.4$) on the line representing Stokes' law (fig. 1) If the law of incline $-\frac{1}{2}$ presents the character of a slip, the law of incline -2, at constant deceleration, presents well the character of a law of transition.

In integrating again the movement starting with the diagram thus developed, one can localize by groping in each case and for each diameter (to a near anomaly) a location of the break C which justifies the observations at four positions; this constitutes a first justification of this diagram.

Note that in following thus the evolution in each case of the velocity of the particles as functions of their abscissas for a given diameter, one respects well the physical aspect of the phenomenon (permanence of one particle of diameter d, discontinuity of one particle to the other) without introducing a restrictive thesis as to the number of parameters in play. However if the relation between C_x and R only become known outside of these two parameters, as constants (which can further conceal the dimensionless groupings of physical size remaing constant in the course of all the experiments) the positions found for the point C should be closely localized. Nevertheless the experiments prove the intervention of other variable parameters. However it must be seen here a second confirmation of the validity of the proposed diagram, the positions found for C rest very close to a line ($C_{xc} \sim 16R_c^{3/4}$) and thus only admit the entry into play of one new dimensionless variable grouping.

The graphic search for the elements of this grouping permits the disentangling of the intervention noticeably exclusive of $u_0 d/\gamma$ which should be taken in its acceptance of Reynolds' relative initial number R_0: the aerodynamic phenomena are then subordinated to the heredity in the explored domain.

Let us recall again the extreme values attained by the principle quantities examined and by the principle dimensionless parameters in the course of these experiments: d, 20 and 120 μ; ρ, 0.69 and 2.50 g/cm^3; θ, 4 and 28°C; p, 323 and 1046 mm Hg; u_0, 30 and 55 m/s; ρ/ρ', 430 and 2200; R_0, 50 and 340; initial u_0/a Mach number 0.088 and 0.164.

It suffices, to complete the numerical results of this analysis and to permit eventual exploitation of it, to give the simple law which determines exactly the initial conditions of the slip: $C_{x_0} \sim 75/R_0$.

Thus, in these measures in a slowly transitory order, it is not the fact, for the order, of not being exactly permanent at one given instant which should justify the slight value observed for C_x at this instant; this latter seems due to the structure of the flow which depends in the first account not on the actual transition but on the former sudden transition (at the time of the very brief establishment of the initial structure, at the introduction of the sphere into the stream).

Footnotes

Meeting of 13 January 1958

(1) R. D. Ingebo, Drag coefficients for droplets and solid spheres in clouds accelerating in airstreams. N.A.C.A., T.N. 3762, Washington, 1956. 31 pages.

*Translator's note: 'the two quantities' translates un couple de valeur, literally 'a pair of amount'.